Scope of Work
Submitted to Whitney Oswald
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Title: TRAX Air Quality Observation Project
Project Period: 15 July 2018-30 June 2019

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1) Project Background

Utah's Wasatch Front experiences poor air quality episodes during both summer and winter due to its unique weather, topography, and pollutant emissions. During winter, inversions trap unhealthy concentrations of fine particulate matter ($PM_{2.5}$), while high pressure during summer leads to elevated ozone (O_3) levels. Spatially-explicit air quality data are needed to help inform the general public on the conditions they are experiencing and help characterize how air pollution affects the public's health. Air quality resources along the Wasatch Front include fixed sites from the Utah Division of Air Quality (UDAQ) and University of Utah (U of U) researchers. Three years ago, we deployed air pollution sensors on two TRAX light rail cars that traverse the Salt Lake Valley on the Red and Green lines. TRAX air quality data have been available to the public to monitor how air quality varies across the Salt Lake Valley at minute-by-minute scales. See http://utahaq.chpc.utah.edu/ and http://air.utah.edu

Only a few mobile urban observation networks leveraging public transit currently exist worldwide: Zurich, Switzerland (Hasenfratz et al., 2015); Karlsruhe, Germany (Hagemann et al., 2014); Oslo, Norway (Castell et al., 2015); and Perugia, Italy (Castellini et al., 2014). Each of these projects have different experimental designs with a different suite of measurements, and while their utility is still being explored, it has been shown that public transit based monitoring can be used to create high-resolution maps of air pollution across urban areas (Hasenfratz et al., 2015). The TRAX air quality monitoring effort is the first to utilize public transit for urban observations of trace species in North America.

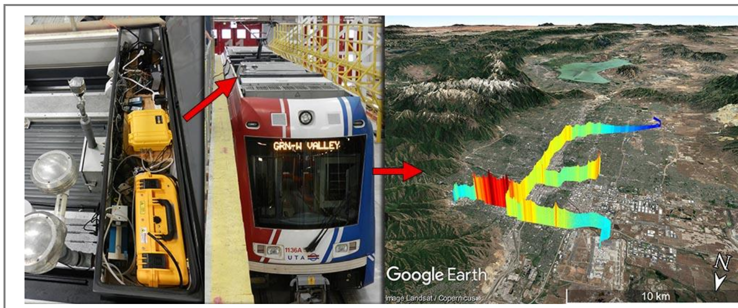

Figure 1. Schematic showing the TRAX instrumentation box, a TRAX train, and a Google Earth plot of the data.

As described by Mitchell et al. (2018), the Utah Transit Authority (UTA) "TRAX light rail train network consists of over 145 electric trains servicing three lines (Red, Green, and Blue) along 94 km of rail track that provide coverage across the SLV (Figure 1). Urbanization along the rail lines varies from dense urban downtown regions to suburban and rural settings, and the train travels on and off major roadways. TRAX operates an older model of rail car on the Blue line, so our data are almost exclusively from the Red and Green lines. Along the Red and Green lines there are 25 and 18 passenger stops, taking 60 and 46 minutes, respectively, to complete a transect on each line. In addition to the spatial coverage, the Red line also provides a 225 m pseudo-vertical profile from the valley floor (1,285 m) to the surrounding mountain foothills (1,510 m). Each TRAX train car covers 18-24 transects when operating for a full day (approximately 18 hours from 5 AM to midnight). During the period December 2014 – April 2017, the trains have been deployed 760 days comprising 10,300 transects (averaging 14 transects a day and deployed 61% of days, or ~4 days a week). When the trains were not in operation, they were often parked outside and therefore became periodic stationary observation sites that provided additional observations."

TRAX is a unique platform available to capture spatial variations in ozone and $PM_{2.5}$ when the light rail cars are operating. The three-year pilot program to test and evaluate the deployment of the sensors and real-time availability of the air quality monitoring has been a success and resulted in legislative support for this project to 1) support the dissemination of the information to air quality decision makers, the public, and researchers, 2) replace and repair aging sensors, 3) apply stringent quality control (QC) measures to the data set, and 4) maintain, calibrate and validate the measurements.

2) Deliverables

The specific deliverables that will be provided during the July 1 2018- June 30, 2019 project period are as follows:

1. Installation of new calibrated $PM_{2.5}$ and ozone sensors on the two TRAX light rail trains
2. Deployment of fixed $PM_{2.5}$ sensors to evaluate the TRAX based measurements against UDAQ measurements at the Hawthorne site
3. Online real-time visualization of TRAX air quality measurements
4. Publicly-accessible archive of TRAX air quality data for download
5. Quality control and rigorous validation of TRAX $PM_{2.5}$ data against UDAQ Hawthorne $PM_{2.5}$ measurements
6. Copy of the quality-controlled data archive for archival with UDAQ
7. Quarterly reports that summarize the status and progress of all aspects of this project
8. Annual report that includes reports on data usage, availability, and validation

Additional details regarding these deliverables follow.

3) Installation of Air Quality Instrumentation on TRAX

The following instrumentation has been proven to be accurate and robust on the TRAX train (Mitchell et al., 2018). The instrumentation currently deployed on TRAX has been heavily used and needs to be replaced. Two TRAX trains (numbered 1136 and 1104) will be outfitted with the new sensors to measure air quality. Electrified trains are an ideal platform for air sampling because they have zero direct emissions and run continuously throughout the day whenever they are operating. The trains have electric circuitry on their roofs in steel weatherproof boxes, and our instruments were installed in one of the spare boxes (dimensions 1.5 m x 0.5 m x 0.5 m). The sample inlets extended 0.5 m above the top of the train through a pipe protruding from the metal box topped with a vent cover and were 4 m above ground level. AC power was provided with a connection into the main power through an inverter. Two generic computer fans provided cooling for the instruments in the box in the summer. Table 1 lists the equipment that will be installed on both of the TRAX trains, as well as the instrumentation sampling frequency and their measurement accuracy.

Table 1
Measurement equipment for $PM_{2.5}$ and Ozone to be purchased and deployed on TRAX train cars.

Instrument	Species	Sampling rate	Measurement uncertainty
Met One Instruments ES-642 Remote Dust Monitor	$PM_{2.5}$	1 sec.	1 µg m^{-3}
2B Technologies Model 205 Ozone Monitor	O_3	2 sec.	2%

4) Data Collection, Storage, Archival, and Dissemination

A key deliverable of the TRAX data system is real-time and archived data available for the public, UDAQ, and other scientists. Part-time technicians will be dedicated to keeping the instruments in working order on both trains at all times, assisting with the fixed calibration sites, and developing the data archive and public access web interfaces (see Section 4). The air quality observations are transmitted to U of U servers via cellular communications every 5 minutes from onboard dataloggers. The data are then archived on Network File System (NFS) mounted servers at the Center for High Performance Computing (CHPC) at the U of U.

The air quality data from this project will then be made available through the following publicly-accessible pathways:

- Real-time webpage display of air quality data for forecasting and decision-making
- Download page to access the entire dataset record or subset of that record
- Quality controlled (QC) data will be made available on the webpage for download once QC procedures have been applied
- Ancillary data on QC procedures and validation results from fixed stations

5) Data Validation, Calibration, and Quality Control Procedures

Figure 2. Example validation $PM_{2.5}$ sensor with a tripod.

A key new component of this study will be establishing careful data validation, calibration, and quality control procedures. For data validation of $PM_{2.5}$ starting with this project, a fixed tripod with an ES-642 $PM_{2.5}$ sensor will be placed at the UDAQ Hawthorne Elementary School site, to provide a baseline comparison of the measurements of the ES-642 Nephelometer to the UDAQ Federal Equivalent Method (FEM) measurements. A second fixed tripod with ES-642 sensors will be placed along the TRAX lines at a central location. Regular calibration, comparison, and validation of the TRAX sensors with the fixed sensors will be carried out. This will allow for careful quantification of any errors and biases in the TRAX measurements relative to UDAQ Hawthorne $PM_{2.5}$ measurements, as well as to ascertain that instrument drift, fog, smoke, and other environmental factors that could potentially impact the TRAX measurements are carefully documented and quantified. The ozone instruments will be calibrated bi-monthly using a calibration unit recently obtained through a University instrumentation grant by the University of Utah Atmospheric Trace gas and Air Quality (U-ATAQ) laboratory (https://air.utah.edu/).

The part-time technicians working on this project will also work to complete the quality control for the data both going forward and for the previous 2014-2018 data record.

6) Performance Measures and Quarterly and Annual Reporting

The performance metrics will focus on the effectiveness of providing the TRAX air quality data set to UDAQ, the public, state government, and scientific community, as well as the quality (calibration and maintenance of instruments) and dependability (no outages) of the data provided. The various performance measures will be summarized in a detailed **annual report** that will be submitted to the Utah Division of Air Quality (UDAQ) that includes:

- Report on the usage of TRAX data for health, air quality or meteorological research, government forecasting, and public awareness.
- Report on the data availability (in percent), with a goal to have as few data outages as possible.
- Calibration metrics of TRAX $PM_{2.5}$ and ozone data as compared to the UDAQ Hawthorne Elementary monitoring site.

In addition to the annual report, we will provide **quarterly reports** that summarize the status of all aspects of this project.

7) Budget (07/15/2018 - 06/30/2019) and Budget Justification

Personnel Costs: Management	$10,214
Personnel Costs: Technician(s)	$18,040
Fringe Benefits (37%)	$10,454
Instrumentation systems (Excluded from Indirect Costs)	$39,200
Lab/technical supplies, and repairs/maintenance	$3,016
Other expenses (cellular modem fees, truck rental, etc.)	$2,640
Total Direct Costs	$83,564
Indirect Costs	$4,436
Total Costs	$88,000

PERSONNEL

Salary support (1 cal. mos. each) for Research Assistant Professors Mitchell and Crosman. Also support for 3 technicians (5 cal. mos. total) to assist with instrument installation and maintenance as well as quality control, calibration, validation, archival, and public dissemination of the data obtained.

FRINGE BENEFITS

The fringe benefit rate for full-time faculty/staff is calculated at 37%.

REPLACEMENT INSTRUMENTATION SYSTEMS total: $39,200

New systems for $PM_{2.5}$ and O_3 on both TRAX light rail trains as well as 2 fixed $PM_{2.5}$ stations at UDAQ Hawthorne Elementary School site as well as a central location along the train tracks.

COMMUNICATION, SUPPLIES, AND OTHER MISC total: $5,656

Monthly cellular modem fees, power inverter, truck rental, miscellaneous cables, tripod and tripod parts, tools, filters, hoses, instrument repairs and maintenance

INDRECT COSTS

University of Utah indirect costs are calculated at a rate of 10.0% of a Modified Total Direct Cost (MTDC).

8) References

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